

# Equipping the Workforce with Space Weather Measurement and Interpretation Skills: THE INCOHERENT SCATTER RADAR SUMMER SCHOOL

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## THE INCOHERENT SCATTER RADAR SUMMER SCHOOL

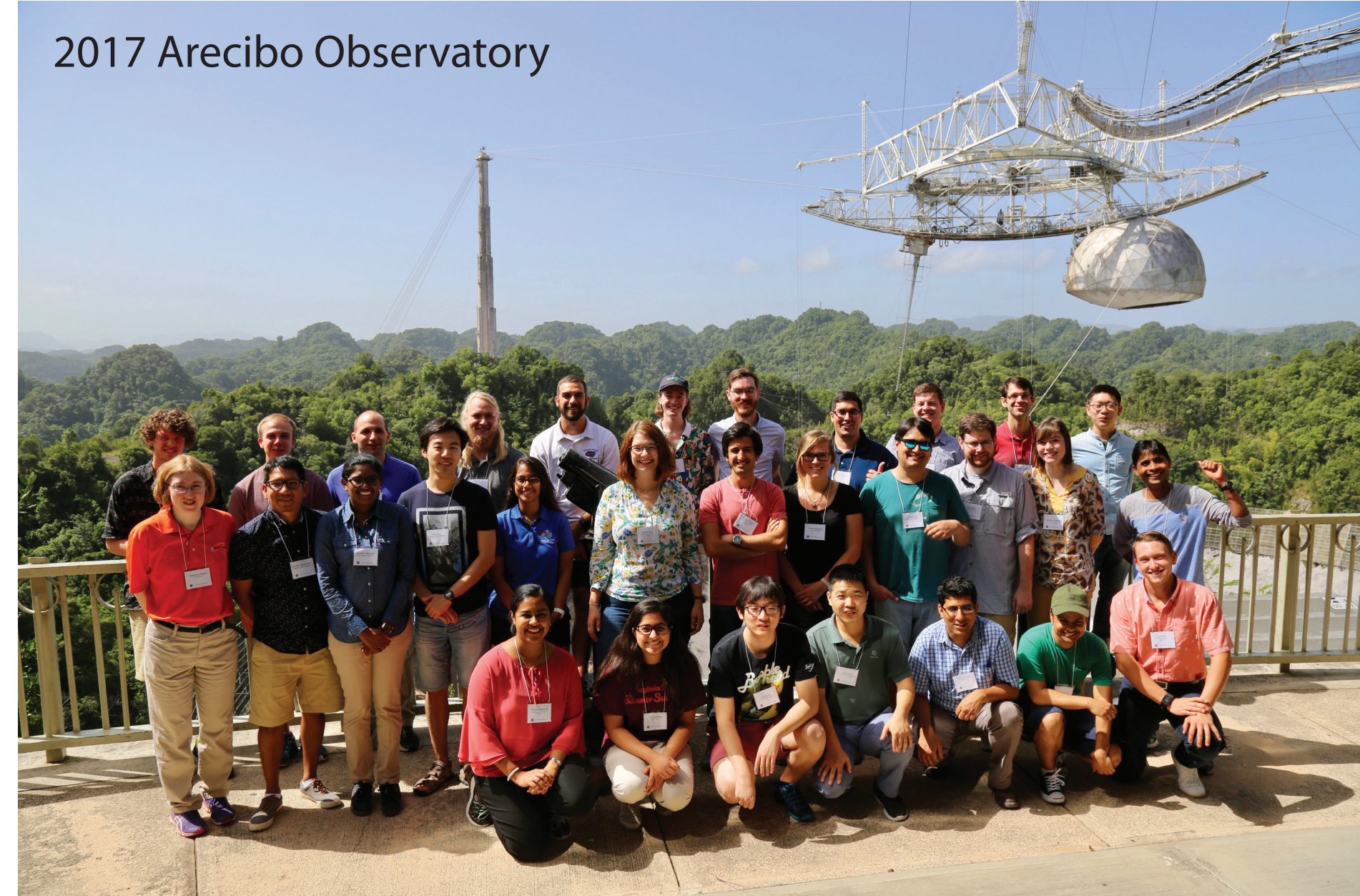


Starting in 2008, MIT and SRI International collaboratively organized a summer school to educate undergraduate and graduate students about ISR theory and techniques, through an intense hands-on program involving a radar experiment and lectures from experts in the field. Over the past eleven years, the program has proven highly successful and is always fully subscribed with both US and international students. Some schools have been held outside the country, and international collaborations on lectures and experiments have been developed. Many students trained in these schools have continued in the field and become a part of the ISR community. The ISR Summer School is a week-long course for undergraduate and graduate students. The students spend the mornings in lectures with experts from the field. In the afternoon, they participate in a hands-on experiment involving data from ISRs around the world.

The core goal of the ISR summer school is to develop a new user base for the facility data and to encourage new participants to enter the field of Incoherent Scatter Radar.

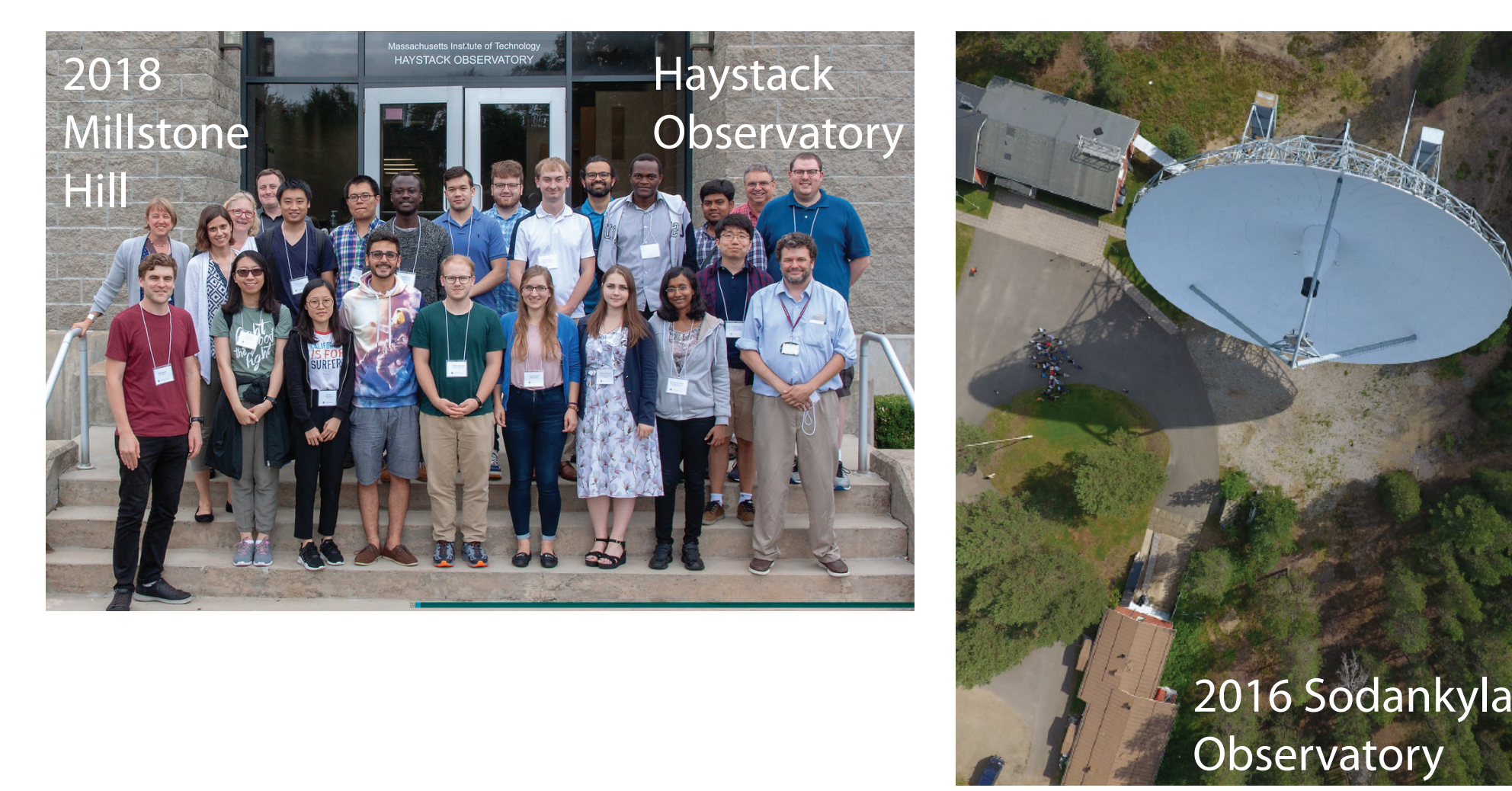
The incoherent scatter radar (ISR) technique provides many significant space weather state variables – e.g. electron and ion density, temperature, and velocity - with unparalleled accuracy and precision. ISR research ranges from space weather forecasting, satellite drag, atmospheric loss, plasma physics, atmospheric turbulence, and communications disruption. The Geospace Facilities (GEO/AGS/GF) program at the National Science Foundation supports several incoherent scatter radar (ISR) facilities worldwide. A community of highly trained scientists operates and uses the data from these radars; however, there is no clear path for graduate students to become a part of this community. While a handful of schools do provide training in ISR theory and techniques, most interested students need to cobble together an educational path for themselves or pursue the program through a postdoctoral position.

Month	Event
September	Final presentation with lecturers, confirm location and date of next school with venue and travel information
December	Meet with lecturers at 2015 meeting. Discuss school updates, logistical details, budget needs, etc. and discuss potential sponsors and other support
January	Finalize sponsor and venue information
February	Finalize sponsor and venue information
March	Application deadline
April	Review applications with lecturers, with students and begin acceptance/acceptance letters. Continue working with venue on preparations
May	Finalize travel tickets and make travel arrangements. Address lecture travel plans. Set up graduate credits with lecturers or make other payment arrangements. Set up meeting with lecturers to discuss agenda and tasks assignments
June	Meet with lecturers at CELEST meeting to discuss agenda and tasks assignments
July	Continue final logistics preparation. School will occur at end of the month. Lecturers will likely fly to the destination during the day to advance lecture materials and prepare and hosting lecturers to support needs
August	Complete school final discussions with lecturers where at school. Decide next school date and discuss next venue. Submit on school's success and improvement needs



July 2018	Sun 22	Mon 23	Tue 24	Wed 25	Thu 26	Fri 27
8:00 AM						
8:30 AM	ISR as a Black Box	ISR Theory 1: Intro to Incoherent Scatter Theory	ISR Theory 2: Statistical Signal Processing	ISR Theory 3: Statistical Signal Processing	ISR Theory 4: Statistical Signal Processing	ISR Theory 5: Statistical Signal Processing
9:00 AM	ISR as a Black Box	ISR Theory 1: Intro to Incoherent Scatter Theory	ISR Theory 2: Statistical Signal Processing	ISR Theory 3: Statistical Signal Processing	ISR Theory 4: Statistical Signal Processing	ISR Theory 5: Statistical Signal Processing
10:00 AM	ISR as a Black Box	ISR Theory 1: Intro to Incoherent Scatter Theory	ISR Theory 2: Statistical Signal Processing	ISR Theory 3: Statistical Signal Processing	ISR Theory 4: Statistical Signal Processing	ISR Theory 5: Statistical Signal Processing
11:00 AM	ISR as a Black Box	ISR Theory 1: Intro to Incoherent Scatter Theory	ISR Theory 2: Statistical Signal Processing	ISR Theory 3: Statistical Signal Processing	ISR Theory 4: Statistical Signal Processing	ISR Theory 5: Statistical Signal Processing
12:00 PM	ISR as a Black Box	ISR Theory 1: Intro to Incoherent Scatter Theory	ISR Theory 2: Statistical Signal Processing	ISR Theory 3: Statistical Signal Processing	ISR Theory 4: Statistical Signal Processing	ISR Theory 5: Statistical Signal Processing
1:00 PM	ISR as a Black Box	ISR Theory 1: Intro to Incoherent Scatter Theory	ISR Theory 2: Statistical Signal Processing	ISR Theory 3: Statistical Signal Processing	ISR Theory 4: Statistical Signal Processing	ISR Theory 5: Statistical Signal Processing
2:00 PM	ISR as a Black Box	ISR Theory 1: Intro to Incoherent Scatter Theory	ISR Theory 2: Statistical Signal Processing	ISR Theory 3: Statistical Signal Processing	ISR Theory 4: Statistical Signal Processing	ISR Theory 5: Statistical Signal Processing
3:00 PM	ISR as a Black Box	ISR Theory 1: Intro to Incoherent Scatter Theory	ISR Theory 2: Statistical Signal Processing	ISR Theory 3: Statistical Signal Processing	ISR Theory 4: Statistical Signal Processing	ISR Theory 5: Statistical Signal Processing
4:00 PM	ISR as a Black Box	ISR Theory 1: Intro to Incoherent Scatter Theory	ISR Theory 2: Statistical Signal Processing	ISR Theory 3: Statistical Signal Processing	ISR Theory 4: Statistical Signal Processing	ISR Theory 5: Statistical Signal Processing
5:00 PM	ISR as a Black Box	ISR Theory 1: Intro to Incoherent Scatter Theory	ISR Theory 2: Statistical Signal Processing	ISR Theory 3: Statistical Signal Processing	ISR Theory 4: Statistical Signal Processing	ISR Theory 5: Statistical Signal Processing
6:00 PM	ISR as a Black Box	ISR Theory 1: Intro to Incoherent Scatter Theory	ISR Theory 2: Statistical Signal Processing	ISR Theory 3: Statistical Signal Processing	ISR Theory 4: Statistical Signal Processing	ISR Theory 5: Statistical Signal Processing
7:00 PM	ISR as a Black Box	ISR Theory 1: Intro to Incoherent Scatter Theory	ISR Theory 2: Statistical Signal Processing	ISR Theory 3: Statistical Signal Processing	ISR Theory 4: Statistical Signal Processing	ISR Theory 5: Statistical Signal Processing

The figure above shows the daily schedule for the 2018 summer school held in Lowell Massachusetts. Half a day (Wednesday morning) is reserved for a teambuilding excursion to allow students to network.



## STUDENT-LED INCOHERENT SCATTER RADAR EXPERIMENTS

### Experiment

On the second day of the school, student groups learn about the radar parameter space and create proposals to answer a relevant science question. That night the experiments are run on the participating radar or radars. A sample proposal is shown below and a group remotely operating the PFISR radar is shown above.

**Experiment Proposal - Group 5**  
 Time: 18:20 to 20:22 UT / 2100-2300 or 2300-0100 EST  
 Location: PFISR

Polar mesospheric summer echoes (PMSE) occurrence is most probable in the period between May and early August in the region between 80 km to 100 km of altitude. The most probable frequency range for PMSE detection is between 50 MHz to 250 MHz. The proposed objective is to characterize PMSE observation at higher frequency using PFISR, as explained below. If we do not detect PMSE, we will concentrate on what we observe which may include sporadic E and particle precipitation.

**Experimental Design:** We want to use PFISR and are basing our experiment off of a previously run experiment ThemisID1 that can be found here: <https://arxiv.org/abs/1508.01807> because of its already proven effectiveness at detecting PMSEs. We plan to use 22 beams in Barker mode to increase the chance of PMSE detection, and examine spatial extent of PMSE, and would like to adjust from long pulse to alternating code to get more ionospheric context. We request the 2nd or 3rd time slot to maximize the probability of detecting PMSEs, which occur most often between 10:00-12:00 AKST according to <https://www.sciencedirect.com/science/article/pii/S1364682610001598>

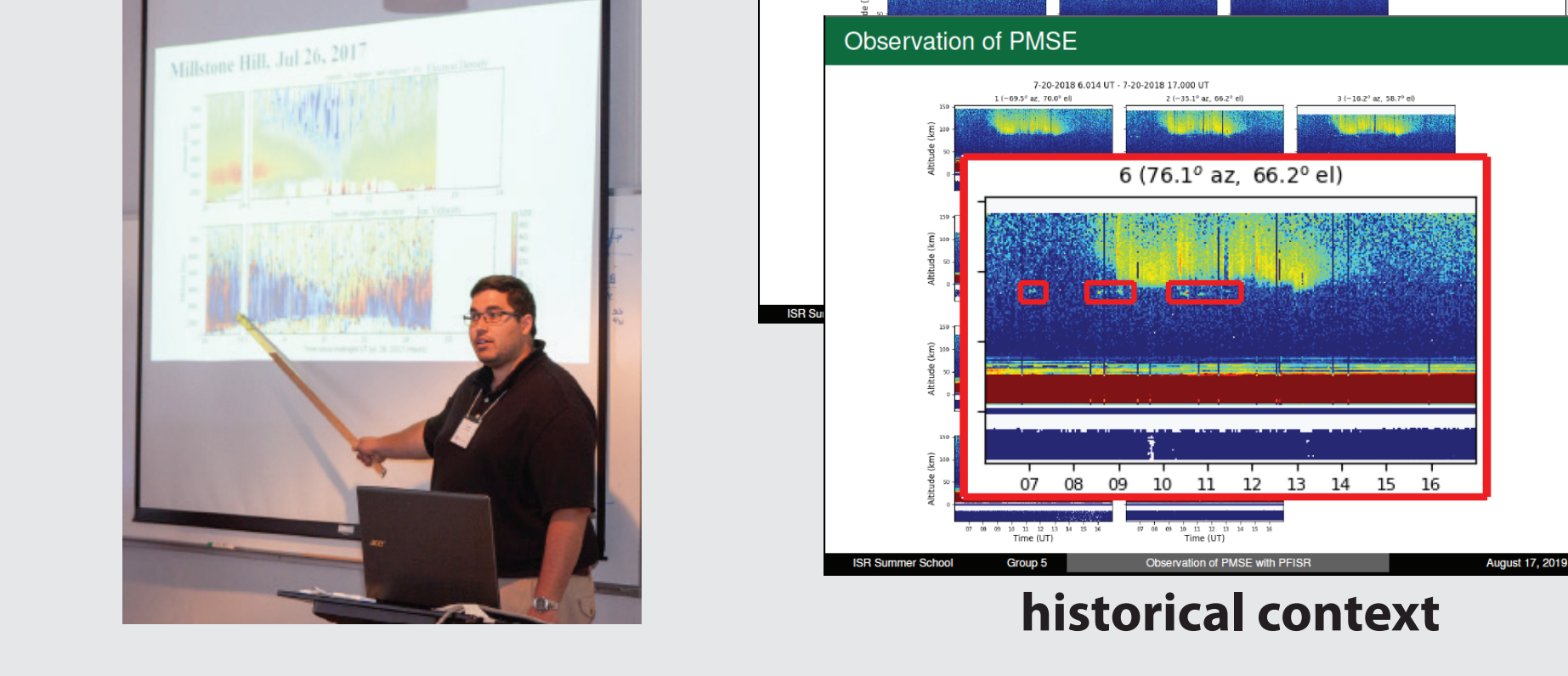
### Data Analysis

Radar site staff process data from the student experiments and submit the data to the Madrigal database by the following afternoon (Day 3). Student download the data using techniques taught during the Madrigal group exercise on Day 1. They then begin to plot data and look for results consistent with their overarching science question. When results are not evident, the students are encouraged to look at similar datasets from past experiments. The lecturers are available throughout the group work time to answer questions and provide mentorship.



### Presentation

The students give presentations on their results on the final day of the school. Every student is required to participate in the presentation. A good example of a group presentation is shown on the right. This presentation shows understanding of the ISR technique, their experiment setup and data analysis in context of historic datasets.



The Radar

- Location: 6° 17' N 147° 25' W
- Geographic Sp. angle: 77° 32'
- Frequency: 1.448 MHz
- Wavelength: λ = 0.567 m
- Range wavelength: λ = 0.3338 m
- Antenna gain: 4.0 dB
- Full width half power antenna beamwidth: 1°

ISR instrumentation

experiment setup

Observation of PMSE

Electron Density - F-layer (1)

Conclusion

- We probed the D, E, and F regions of ionosphere with an advanced experimental set up of PFISR. However, we did not observe any PMSE structure.
- The electron density obtained from the lower ionospheric regions was relatively noisy.
- Using both ground and space based instruments, we showed that the geomagnetic condition of the ionosphere on 20180713 was relatively quiet.
- In addition to the radar data, the data obtained from these ground and space based instruments help us to verify that there was no favourable ambient condition for the formation of PMSE.
- We demonstrate that the advanced set up of PFISR radar can be used to obtain the altitude, latitude and time variation of plasma parameters of the ionosphere.

historical context

data analysis conclusions

## LECTURES BY FACILITY PRINCIPAL INVESTIGATORS AND FIELD EXPERTS

**The Need for Statistical Descriptions of ISR Signals**

If I know the position of every single electron in the scattering volume, I would know the received voltage exactly.

Exact expression for scattered electric field as a superposition of Thomson scatterers:

$$E_s = \frac{1}{4\pi\epsilon_0} \sum_{i=1}^N \frac{q_i \mathbf{r}_i}{r_i^3} \cdot \mathbf{E}_i$$

ISR theory predicts statistical aspects of the scattered signal:

Scattered Power:  $\langle P_s(t) \rangle = \langle P_s(t - \tau) \rangle$

Autocorrelation Function:  $\langle P_s(t) P_s(t - \tau) \rangle$

These statistical properties are functions of macroscopic properties of the plasma:  $N_e, T_e, T_i, n_{e0}$

**Rough Detectability Calculations**

Radar Equation:

$$P_s = P_t \frac{G^2 \lambda^2 \sigma}{(4\pi R)^4}$$

For a distribution of electrons:

$$P_s = P_t \frac{G^2 \lambda^2}{4\pi R^4} \frac{1}{2} \frac{N_e n_{e0}^2 \tau^2}{2} \frac{4\pi}{G}$$

For  $P_t = 1 \text{ MW}$ ,  $N_e = 10^{11} \text{ m}^{-3}$ ,  $\tau = 500 \text{ ns}$ ,  $R = 300 \text{ km}$ ,  $\lambda = 0.6 \text{ m}$ ,  $A_{\text{max}} = \frac{1}{2} \lambda^2$ , and a dish diameter of  $d = 300 \text{ m}$ , this gives:

$$P_s = 2.81 \times 10^{-14} \text{ W}$$

For a smaller radar with  $d = 30 \text{ m}$ ,  $P_s = 2.81 \times 10^{-16} \text{ W}$

**The ISR Signal Processing Chain**

Signal Voltages → Noise Voltages → Noise ACF → Filter → Predicted Lag Products

ISR Theory → Ambiguity Functions → Lag Products

The school is structured with lectures in the mornings and experiment group work in the afternoons. Lectures begin with introductory material about the ionosphere and radars. Then incoherent scatter theory is introduced and supporting topics are explored in more detail. Each school also has lectures on science relevant to the hosting radar facility. The final day includes an extended question and answer session where students are able to ask the lecturers about any topic previously discussed in the school.



Lecture topics include:

- Intro to the Ionosphere
- Radar Physics
- ISR Theory
- Statistical Signal Processing
- Data Analysis and Fitting
- Phased Arrays

Evaluations are collected and analyzed each year. The program is updated accordingly. One such addition to the school is shown in the two panels on the right. MIT Haystack developed a "black box" ISR where students are able to input ISR variables and see how the system would respond. This gives students a chance to learn how the ISR specifications determine the types of measurements that can be made.

Treat ISR as a blackbox

- What are the science outputs?
- What knobs can you turn at the input?
- For an existing ISR
- If you got to build a new ISR
- Try it yourself with two on-line tools
- Existing and new ISR simulators

Blackbox Performance Predictor for a new ISR (single-mode)

Choose ISR freq in MHz: 440.000    Choose aperture in m: 100.000

ISR latitude in deg: 45    ISR longitude in deg: 180

ISR power in Watts: 1000    ISR pulse length in sec: 40000.0

Choose UT start date and time:    Month:    Day (1-31):

Choose UT start hour (0-23):    Set number of hours to run: 24

Elevation (0-90): 90    Set number of beams to integrate: 90

Days cycle (0-31): 244    Calculate ISR performance

Error percentage for ISR ACF

Alt limited by PP

Altitude in km: 0 to 2500

Hours since UT month=12, day=12, hour=0

Start: 2018-07-12 00:00:00    Stop: 2018-07-12 00:00:00

Start month=12, start day=12, start hour=0, start min=0, start sec=0, total hours=24, n\_beams=90, n\_cycles=900



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